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UNCLASSIFIED CRREL-SR-80-37 NL

Special Report 80-37

November 1980

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EFFECTS OF A TUNDRA FIRE ON SOILS AND PLANT COMMUNITIES ALONG A HILLSLOPE IN THE SEWARD PENINSULA, ALASKA

AD A094607

Charles Racine

Prepared for
DIRECTORATE OF MILITARY PROGRAMS
OFFICE OF THE CHIEF OF ENGINEERS
By
UNITED STATES ARMY
CORPS OF ENGINEERS
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE, U.S.A.

CRREL

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER Special Report 80-37	2. GOVT ACCESSION NO. AD-A094607	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EFFECTS OF A TUNDRA FIRE ON SOILS AND PLANT COMMUNITIES ALONG A HILLSLOPE IN THE SEWARD PENINSULA, ALASKA.		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Charles Racine		8. CONTRACT OR GRANT NUMBER(s) DACA 89-79-M-1816
9. PERFORMING ORGANIZATION NAME AND ADDRESS		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS DA Project 4A161102AT24 Scientific Area A2 Work Unit 002
11. CONTROLLING OFFICE NAME AND ADDRESS Directorate of Military Programs Office, Chief of Engineers Washington, D.C. 20314		12. REPORT DATE November 1980 13. NUMBER OF PAGES 26
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire 03755		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Cold regions
Wilderness
Ecosystems
Fires
Permafrost
Soils

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

During summer 1977, wildfires burned extensive areas of low arctic tundra in the Seward Peninsula, Alaska. The present study was initiated in July 1978 to determine the effects of these fires on tundra soils and vegetation. Nine 10- x 1-m permanent transects were established at regular intervals along the topographic gradient of a burned hillslope in the central Seward Peninsula near Imuruk Lake. Soil characteristics and plant species density and cover were determined in each of the 90 1- x 1-m plots on this slope during July of both 1978 and 1979.

Soils and vegetation had been quantitatively sampled on this slope in 1973,

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Abstract (cont'd)

thereby providing pre-fire comparisons; a sedge tussock-shrub tundra community with mud circles occupied the poorly drained footslope and a birch and ericaceous shrub tundra community with elongate turf-banked frost boils had developed on the moderately well drained backslope. The broad, poorly-drained summit was occupied by sedge-shrub tundra with low-centered polygons.

The severity of burning in July 1977 varied along this slope with moderate to heavy burning of the birch and ericaceous shrub tundra and light to moderate burning of the sedge tussock-shrub tundra and sedge-shrub tundra communities. Post-fire (1978 and 1979) changes in plant cover, species composition and soil thaw depths are shown to vary with position on the slope and burning severity. The relationship of these changes to natural succession in the absence of fire is discussed.

PREFACE

This report was prepared by Dr. Charles Racine, Johnson State College, Johnson, Vermont, for the Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding was provided by DA Project 4A161102AT24, *Research in Snow, Ice and Frozen Ground*, Scientific Area A2, *Cold Regions Environment Interactions*, Work Unit 002, *Cold Regions Environmental Factors*.

Leslie A. Viereck, U.S. Forest Service and Larry Johnson, CRREL reviewed this report for technical accuracy.

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INTRODUCTION

Although generalizations about the disturbance and recovery of arctic tundra vegetation and ecosystems have been made (Johnson and Van Cleve 1976, Webber and Ives 1978), it is apparent that the responses to a disturbance vary drastically among different ecosystems and different areas. This study describes and compares the effects of fire on soils and permafrost, and describes post-fire revegetation patterns of arctic tundra communities on a hillslope in the Seward Peninsula of northwestern Alaska.

Widespread lightning-caused tundra fires in July and August 1977 burned over one million acres in northwestern Alaska (Fig. 1). Studies to determine the effects of these fires on vegetation, soils and permafrost were initiated one year later in July 1978 at Imuruk Lake in the Seward Peninsula (Racine and Racine 1979, Racine 1979). Permanent plots were established and sampled during the summers of 1978 and 1979. This report describes the results of monitoring post-fire changes in thaw depths and plant species composition and cover in the Seward Peninsula during the 1978 and 1979 growing seasons. A similar study of tundra fire effects by Hall et al. (1978) was initiated immediately following the fire in August 1977 at the Kokolik River (69°30'N, 161°50'W) near the boundary of the Arctic Coastal Plain and the Northern Foothills (Fig. 1).

STUDY AREA

The Imuruk Lake area is located in the central Seward Peninsula (65°35'N, 163°10'W; Fig. 1). The rolling, unglaciated landscape here supports low arctic tundra ecosystems dominated by sedge tussock-shrub tundra communities. The only long-term climatic data available for this area come from stations at Nome and Kotzebue, which have maritime conditions in contrast to the more continental climate in the Seward interior around Imuruk Lake. Hopkins and Sigafoos (1951) characterize the climate around Imuruk Lake as rigorous and continental, with a mean annual temperature of -6.7°C and a mean annual precipitation of around 21 cm, of which approximately 25% falls as snow. More than 50% of the annual precipitation occurs during a well-defined rainy season extending from July through September. Subfreezing temperatures predominate from early October to mid-May. The July mean temperature is near 10°C; however, nocturnal frosts are common during all of the summer months. The treeline approaches to within 25 km of Imuruk Lake.

The most intensive studies were carried out at nine sites along a topographic transect, running from the bottom (320 m) to the crest (440 m) of Nimrod Hill, which borders the east side of Imuruk Lake (Fig. 2 and 3). This area was chosen because of pre-fire studies of soils and vegetation carried out along this same transect in 1973 by Holowaychuk and Smeck (1979) and Racine and Anderson (1979). These studies provided a pre-fire control as well as a basis for evaluating the effects of the 1977 tundra fire.

Nimrod Hill (Fig. 2) is located within the lava plateau physiographic region of the Seward Peninsula (Hopkins 1963). The most conspicuous relief features here are isolated hills with broad, dome-shaped summits and smooth slopes which are rarely steeper than 18%. The transect begins on a Pleistocene terrace adjoining Imuruk Lake and extends northeast up the southwest sideslope and over the crest onto the northeast-facing side of Nimrod Hill (Fig. 3). The bedrock

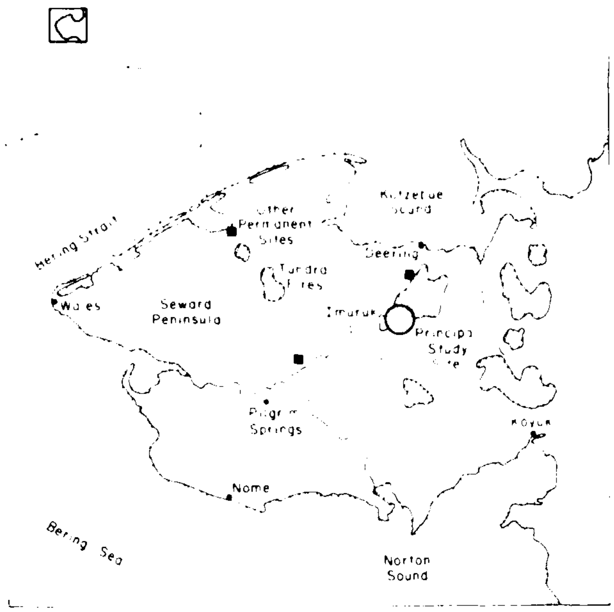

Figure 1. Map of the Seward Peninsula, Alaska, showing size and location of 1977 tundra fires.

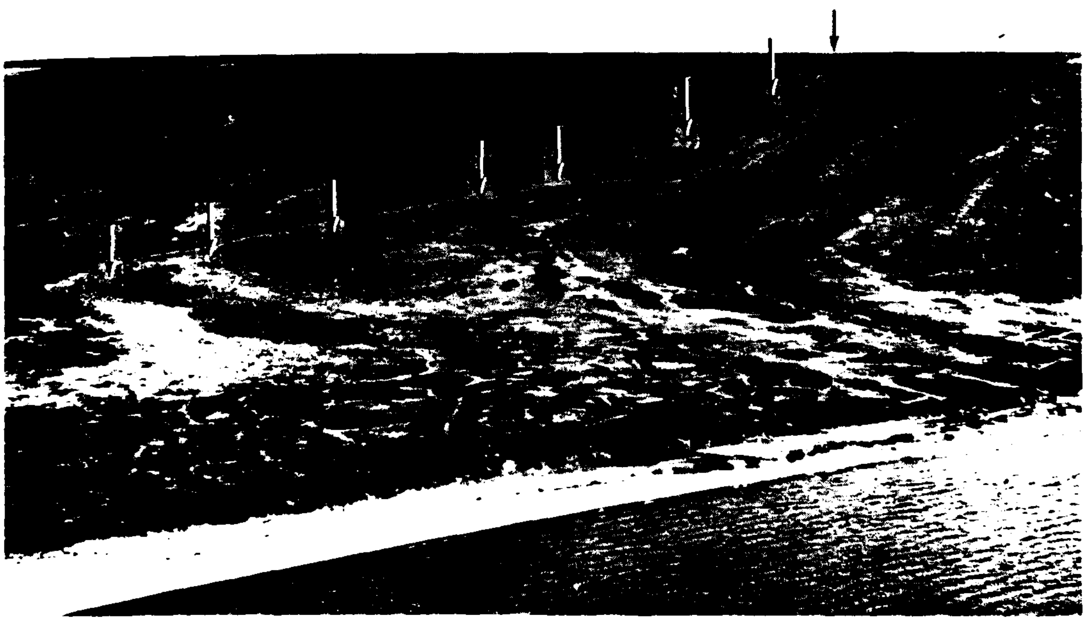

Figure 2. Postfire (July 1978) aerial oblique view of Nimrod Hill slope where nine permanent plot study sites were established along a topographic transect (eight sites marked). Sandy shore of Imuruk Lake is visible in the lower foreground.

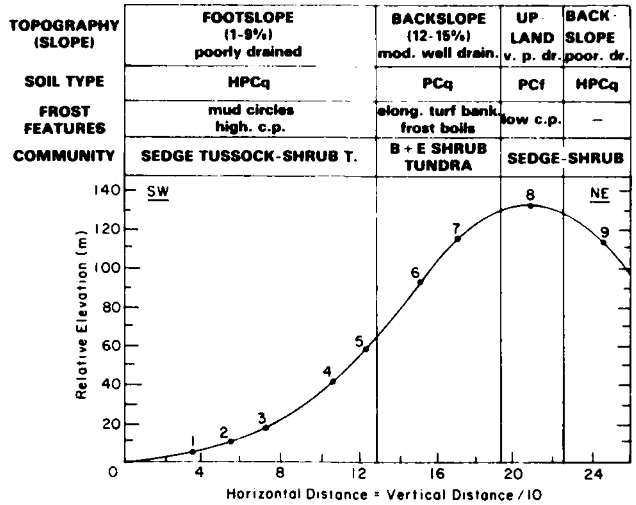

Figure 3. Scaled topographic profile of Nimrod Hill near the east shore of Imuruk Lake. Location of nine study sites shown together with topography, slope, drainage, soil types (HPCq = Histic Pergelic Cryaquept; PCq = Pergelic Cryaquept; PCf = Pergelic Cryofibrist), frost features (c.p. = centered polygons) and plant community type (B+E = Birch and ericaceous). Elevations range from 335 m (1100 ft) at site 1 up to 457 m (1500 ft).

of Nimrod Hill was shown by Hopkins (1963) to be quartz monzonite which was not buried under the plateau lavas. As depicted in Figure 3, the transect profile is sigmoid in form, starting with a gentle gradient (1–9%) on the footslope, then increasing in steepness on the convex backslope (12–15%) and rising to the broad, level crest. The flexure in slope curvature near site 5 appears to coincide with a fault, identified by Hopkins (1963), a short distance to the north.

Shallow, weakly expressed, more or less parallel drainageways occur at intervals of about 100 to 150 m along the entire southwest-facing slopes of Nimrod Hill (Fig. 2). Low (1–2 m) willow shrub thickets occupy these drainageways. The intervening interfluves are slightly convex, with the sideslopes having a gradient of only a few percent. The transect is located approximately along the axial crest of one of these interfluves.

Soil moisture environments along the transect range from moderately well-drained on the southwest backslope (sites 6 and 7) to very poorly drained on the level crest (site 8) of Nimrod Hill (Fig. 3). The footslope between sites 1 and 5 and the northeast-facing backslope are poorly drained. At all sites along the transect, the soil moisture environment is well expressed by the color of the mineral soil; a gray, gley-soil predominates on poorly drained sites with a yellowish mottling increasing in extent with improved drainage above site 5, up to the level crest (Holowaychuk and Smeck 1979). The texture of the soil mineral fraction also changes along the transect from a coarse loam on the backslope to a silt clay loam on the colluvial footslope. Soil taxonomic units along the transect correspond with the soil moisture environments (Fig. 3): Histic Pergelic Cryaquepts on the poorly drained footslope, Pergelic Cryaquepts on the moderately well drained backslope, and Pergelic Cryofibrists on the very poorly drained level upland.

A variety of cryogenetic features are evident along the transect (Fig. 2 and 3). Along the nearly level crest of Nimrod Hill, these features consist of low-centered polygons, 10 to 15 m across. On the upper portion of the backslope, elongate, turf-banked, nonsorted frost boils are common. In the vicinity of site 7 these longitudinal features are up to 3 m in diameter and occupy 40% of the area (Fig. 11). Although of considerable extent, these frost boils were not very active as of 1973, since patches of lichens and other vegetation covered most of the surface. On the footslope, between sites 5 and 1, equidimensional

mud circles and some weakly expressed, benched solifluction forms represent the main cryogenetic features. These mud circles are usually less than 1 m in diameter, few in number and cover less than 3% of the area. In 1973, their surfaces were covered with a thin mat of fine moss. Along with these mud circles, high-centered polygons occupy the level base of the footslope and terrace at site 1 (Fig. 2).

Corresponding with the above-described changes in topography, soil moisture environments, soil types and cryogenetic features are changes in the plant communities along Nimrod Hill (Fig. 3). These were quantitatively sampled and described before the fire in 1973 and are the basis for the following descriptions; more detailed information on pre-fire communities are provided in the *Results* section (cf. Fig. 4). Nomenclature for plant community names follows Viereck and Dyrness (1980).

The footslope from site 1 to site 5 is occupied y sedge tussock-shrub tundra dominated by cottongrass tussocks (*Eriophorum vaginatum*); dwarf shrubs such as Labrador tea (*Ledum palustre*), dwarf birch (*Betula nana*), cloudberry (*Rubus chamaemorus*), lingonberry (*Vaccinium vitis-idaea*), blueberry (*V. uliginosum*) and crowberry (*Empetrum nigrum*); the mosses *Sphagnum* spp., *Dicranum elongatum, Hypnum pratense* and *Aulocomium palustre;* and lichen species, *Cladonia gracilis, C. rangiferina, Cetraria cucullata, C.islandica* and *Peltigera aphthosa*.

Above this sedge tussock-shrub community is a birch and ericaceous shrub tundra community on the better-drained backslope (sites 6 and 7). This community is composed of the same dwarf shrub species as found in the tussock-shrub community (with the exception of cloudberry). *Carex bigelowii* replaces cottongrass tussocks here and lichens are more important than mosses. The composition of this community changes slightly on the tops of the elongate frost boils.

On the level crest of Nimrod Hill (site 8) a sedge-shrub tundra community includes sedges of the species *Carex aquatilis* and *Eriophorum scheuchzeri*, as well as cloudberry, dwarf birch, Labrador tea, and lingonberry; *Sphagnum* moss is more important here than in the other communities along the slope. On the northeast-facing backslope of Nimrod Hill (site 9), just below the crest, there is a sedge-shrub tundra community similar to that on the crest except that sedges are less abundant and moss cover more conspicuous. All of the above ecosystems burned during the 1977 tundra fire.

METHODS

To study the effects of tundra fire on a range of ecosystems, a series of permanent plots was established at each of the nine sites along the Nimrod Hill transect in July 1978 (Fig. 3). The transect and sites were located as close as possible to their 1973 positions for comparative purposes. At each of the nine slope positions, two stakes were placed 10 m apart, perpendicular to the contours, and a meter tape stretched between them. Then 10 sample plots, with dimensions of 1 m × 1 m, were positioned between the stakes using the tape as one side. In each of the 90 sample plots on 14-17 July 1978 and 25-29 July 1979, all living plant species were recorded, an estimate of percent cover made, and the number of leafy live shoots or stems counted for each species. Thaw depths were determined by probing the center of each 1-m × 1-m plot while soil pits were dug nearby to determine the thickness of the organic horizon. A comparison of the organic layer thickness before (1973) and after the fire was used to evaluate the severity of burning using the following rating system developed by Viereck et al. (1979):

1. Heavily burned—soil organic material completely or nearly consumed to mineral soil, no discernible plant parts remaining.
2. Moderately burned—organic layer partially consumed, parts of woody twigs remaining.
3. Lightly burned—plants charred but original form of mosses and twigs visible.
4. Scorched—moss or other plants brown or yellow but species usually identifiable.
5. Unburned—plant parts green and unchanged.

The patterns of recovery observed at Imuruk Lake were compared with other observations and permanent plots established near Utica Creek on the same 1977 burn, on a different burn near the Arctic River, and on an older 1971 tundra fire site about 100 km north of Nome (Fig. 1).

For each site, thaw depths, cover, and density values for each species in the 10 sample plots were averaged. Where plots were on frost features, such as mud circles or frost boils, values for these plots were computed separately. Standard deviations were also obtained for the mean values. Paired t-tests (Ostle 1963), comparing 1978 and 1979 values for each plot, were used to determine significant changes in species cover,

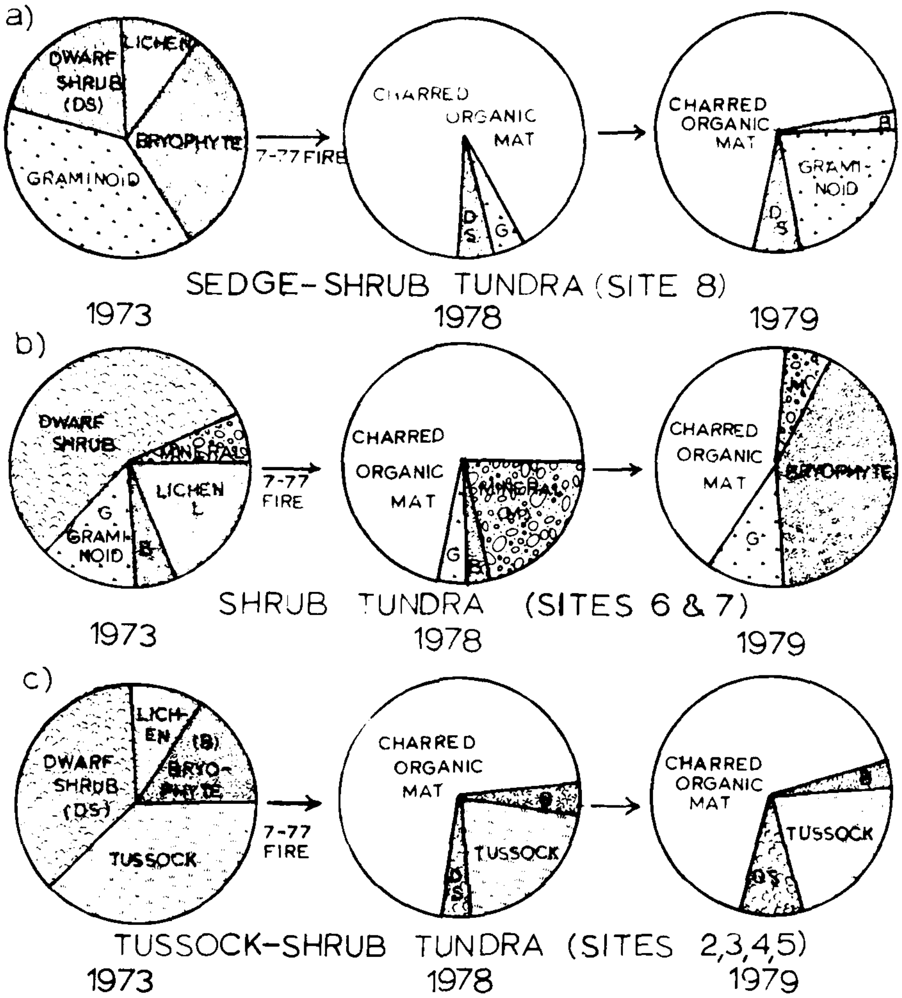

Figure 4. Contributions of different plants to total ground cover (whole circle = 100%) before the tundra fire on Nimrod Hill in July 1973 (left side), one year after the fire in July 1978 (center), and two years after the fire in July 1979 (right side). Shown for three communities at the top (a), middle (b) and bottom (c) of Nimrod Hill. (B = Bryophyte, G = Graminoid, DS = Dwarf shrub, M = Mineral soil.)

density and thaw depths. Since cover values for all species were very low following the fire, shoot density values were generally considered more sensitive indicators of change.

RESULTS

Sedge tussock-shrub tundra (sites 1, 2, 3, 4, 5)

Soils

On the footslope of Nimrod Hill, the poorly drained soils on a slope of 2 to 9% included a pre-fire organic horizon, 25-30 cm thick (27.9 ± 5.3 cm; n = 18), overlying frozen colluvial mineral silt clay loam. The measurement of organic horizon thickness in 1978, one year after the fire in the tussock-shrub tundra, suggested removal of only 5 cm or less of this organic horizon and a light severity of burning. Mud circles 0.5 to 2 m in diameter are common and in 1973 were usually occupied by groups of vigorous cottongrass tussocks with a thin moss cover over the intertussock mineral soil. This moss mat was completely removed by the 1977 fire.

Mid-July thaw depths in tussock-shrub tundra did not appear to be significantly greater one

year after the fire (28.5 cm) than before the fire (27.6 cm) at site 2 (Table 1). However, from 1978 to 1979 thaw depths increased significantly at all five tussock-shrub tundra sites: by 30-45% in non-mud-circle areas, and by 12-20% on mud circles (Table 1). There is evidence obtained by Schmitt (1979) to further support the idea that this increase in thaw depths is due to fire effects rather than to yearly climatic fluctuations. This evidence includes 1) measurements of thaw depth in an area of unburned tussock-shrub tundra near Nimrod Hill in July 1979 (28.9 ± 7.6 cm) which were significantly less than on the nearby burned tussock-shrub tundra (35.8-49.0 cm, Table 1), 2) a bulldozed firebreak which had been cut through tussock-shrub tundra during the 1977 fire north of Imuruk Lake, where thaw depths were 40% deeper on the burned side (53.3 ± 5.8 cm) than on the unburned side (38.0 ± 5.8 cm). (In the bulldozed fireline, thaw depths in July 1979 were 46.3 ± 5.6 cm.) In mid-July of both 1978 and 1979, the upper mineral soil horizons thawed at most tussock-shrub tundra sites sampled. This condition was rare or unknown in 1973 (Holowaychuk and Smeck 1979) and is attributed to the cumulative effects of burning, such as the reduction in the thickness of the organic mat.

Vegetation

Living plant cover was drastically reduced by the 1977 fire; however, small patches of unburned or scorched vegetation were common, particularly on the lower slope at sites 1, 2 and 3 (Table 2). One year later, in July 1978, about a 23% living plant cover was reestablished in this community (Table 2, Fig. 4). This rapid recovery is mainly due to the resprouting of cottongrass tussocks within one year following the fire (Fig. 4, 5 and 7). Dwarf shrubs were slower to resprout, reaching cover values of only 3 to 7% in 1978 (Fig. 4). Colonization of the intertussock spaces by bryophytes and graminoid seedlings also contributed small amounts of living plant cover to the first year recovery (Fig. 4).

Between the first and second years following the fire, total plant cover increased slightly by 8 to 10% at three of the five tussock-shrub tundra sites (Table 2, Fig. 4, 6 and 8). This increase was mainly due to additional resprouting of dwarf shrubs rather than cottongrass tussocks (Fig. 4). During the second year there was also a small increase in bryophyte cover while sedge seedlings remained abundant. No lichen recovery was observed at any tussock-shrub tundra site although small unburned patches were common at site 1.

Post-fire contributions to cover and shoot density varied among several species which generally were important in the tussock-shrub community before the fire (Table 3) and colonizers not seen at these sites before the fire. These colonizers included bluejoint grass (*Calamagrostis canadensis*), fireweed (*Epilobium angustifolium*), and the bryophytes, *Marchantia polymorpha*, *Ceratodon purpureus* and *Polytrichum juniperinum*. However, none of these colonizers reached high cover values during the first or second years following the fire. Of the graminoid species, cottongrass tussocks were clearly the most vigorous resprouter. Resprouting shoots of *Carex bigelowii* and/or *C. aquatilis* were always present but scattered. Bluejoint grass formed small, localized colonies and made significant increases in density from 1978 to 1979 at site 3 (Table 3). Seedlings of both *Carex bigelowii* and *Eriophorum vaginatum* were fairly abundant in intertussock spaces during both 1978 and 1979, however, two-year-old tillering seedlings of these species were found only occasionally in 1979, suggesting low seedling survival from the first to the second year following the fire.

Of the resprouting dwarf shrubs in Table 3, the species which showed the greatest increase in cover and/or density during the first two years following the fire were, in order of importance: cloudberry, Labrador tea, lingonberry, blueberry, dwarf birch, willow and crowberry (Table 3). Cloudberry shoot density increased by an average of 34 shoots/m² (200%) between 1978 and 1979 at four of the five tussock-shrub tundra sites. Labrador tea shoot density also increased significantly at four out of five sites by an average of 49 shoots/m² (65%). Lingonberry shoot density increased significantly at two out of four sites from 43 shoots/m² to 126 shoots/m² in 1979 at site 2 and from 26 shoots/m² to 43 shoots/m² at site 3. Significant increases in blueberry shoot density occurred only at the two better-drained tussock-shrub tundra sites: 4 and 5.

Resprouting dwarf birch occurred sporadically, usually at a frequency of less than 50%. However, during 1979 dwarf birch resprouts appeared in plots where they were not present in 1978, unlike the other dwarf shrub species which had appeared in most plots during the first year following the fire. Crowberry did not appear in any plot following the fire, although it was common in the pre-fire tussock-shrub tundra in 1973.

The most striking visual change in tussock-shrub communities between 1978 and 1979 was the increased density of fruiting stalks of cottongrass tussocks (Table 4, Fig. 6 and 8). In 1978, cot-

Table 1. Mean thaw depths (cm) in frost-scarred (mud circles, frost boils) and non-frost scarred plots established at nine sites (three communities) along the topographic gradient of Nimrod Hill before and after a 1977 tundra fire.

	*Thaw depth**						*Increase in thaw depth*					
	Prefire (1973)		*1 yr after (1978)*		*2 yrs after (1979)*		*1973-78*		*1978-79*		*1973-79*	
Site	*Mean*	*Std. dev.*	*Mean*	*Std. dev.*	*Mean*	*Std. dev.*	*(cm)*	*(%)*	*(cm)*	*(%)*	*(cm)*	*(%)*
Sedge Tussock-Shrub Tundra												
Site 1												
Non-mud circle	ND		29.5	6.7	38.2	8.6	ND		+8.7	29	ND	
Mud circle	ND		57.5	3.5	69.0	1.4	ND		+11.5	20	ND	
Site 2												
Non-mud circle	27.6	5.6	28.5	4.7	41.2	5.8	+0.9	3	+12.7	45	+13.6	49
Mud circle	44.5		45.0	6.1	50.5	6.4	+0.5	1	+5.5	12	+6.0	13
Site 3												
Non-mud circle	ND		27.2	3.8	35.8	3.8	ND		+8.6	32	ND	
Mud circle	ND		44.4	6.3	52.8	4.5	ND		+8.4	19	ND	
Site 4												
Non-mud circle	ND		32.4	6.1	44.8	5.5	ND		+12.4	38	ND	
Site 5												
Non-mud circle	ND		37.7	4.0	49.0	4.5	ND		+11.3	30	ND	
Birch and Ericaceous Shrub Tundra												
Site 6												
Non-frost boil	24.6	5.7	53.8	4.5	68.0	9.8	+29.2	119	+14.2	26	+43.4	81
Frost boil	43.2	9.9	65.0		Rock		+21.8	50	Rock		Rock	
Site 7												
Non-frost boil	ND		60.0		Rock		+35.4	114	Rock		Rock	
Frost boil	ND		Rock		Rock		Rock		Rock		Rock	
Sedge-Shrub Tundra												
Site 8												
Non-frost scar	23.5	2.9	31.1	2.9	42.6	1.9	+7.6	32	+11.5	37	+19.1	81
Site 9												
Non-frost scar	21.9	3.7	25.9	2.9	37.5	4.6	+4.0	18	+11.6	45	+15.6	71

*For one to ten 1-m × 1-m plots at each site.
ND = No determination.

tongrass fruiting stalk density was about 2-6/m², but one year later in the same plots, densities had increased by ten times to 20-60/m².

Birch and ericaceous shrub tundra (sites 6 and 7)

Soils

In 1973, the steeper, moderately well-drained backslope of Nimrod Hill was occupied by a birch and ericaceous shrub tundra community with well-vegetated, elongate, turf-banked frost boils 1 m to 2 m in diameter (cf. Fig. 11). Organic horizons were thin (0–5 cm) over these frost boils, but thicker (18–20 cm) in the surrounding unscarred area. One year after the 1977 fire, it was apparent that the fire had removed all of the vegetation and soil organic matter from these frost boils (Fig. 11). In the surrounding birch and ericaceous shrub tundra, all of the aboveground vegetation and about 50% of the organics had burned, leaving an 8- to 10-cm organic horizon. Hence, the severity of burning was heavy on the frost boils and moderate to heavy in the surrounding area. Because of the absence of resprouting tussocks, the exposed mineral soil surface on the frost boils (occupying up to 40% of the area), and the blackened/charred organic mat, this backslope area appeared to be the most severely burned part of the transect in 1978 (Fig. 2).

Pre-fire thaw depths in mid-July 1973 on the backslope were about 24.6 ± 5.7 cm in the non-frost-boil areas and 43.2 ± 11.3 cm on the elongate, turf-banked frost boils (Table 1). In July 1978, thaw depths had increased by about 123% (to 54.8 ± 7.0 cm) in the non-frost-boil areas and by 50% (to 65 cm) in the exposed frost boils, however, rock was encountered before thaw depth measurements could be made in many plots. By July 1979, it was almost impossible to obtain thaw depth measurements because of rock. In addition, there was apparent subsidence

Table 2. Cover values* for plant growth forms at eight sample sites along the topographic gradient of Nimrod Hill in the Seward Peninsula, Alaska, before and after a 1977 tundra fire on this slope.

Plant growth form	*Prefire (1973)* Cover (%)	±1 std. dev.	*1 yr after (1978)* Cover (%)	±1 std. dev.	*2 yrs after (1979)* Cover (%)	±1 std. dev.	*Diff. between 1978 and 1979 average cover values*†
Sedge Tussock-Shrub Tundra							
Site 2							
Graminoid	43.2	17.7	18.7	8.0	21.5	10.8	2.8
Dwarf shrub	39.4	20.9	3.3	1.3	9.3	3.3	$6.0^{.001}$
Bryophyte	2.8	4.7	1.0	0.2	2.7	1.7	$1.7^{.01}$
Lichen	5.5	4.1	0.0		0.0		0.0
Total	90.9		23.3		32.2		$8.9^{.01}$
Site 3							
Graminoid	ND		21.1	17.7	21.4	20.5	0.3
Dwarf shrub	ND		5.7	3.3	6.2	3.4	0.5
Bryophyte	ND		1.0	0.5	2.5	1.4	$1.5^{.01}$
Lichen	ND		0.0		0.0		0.0
Total	ND		27.8		30.1		2.3
Site 4							
Graminoid	ND		9.7	6.0	10.1	6.9	$4.8^{.001}$
Dwarf shrub	ND		7.0	3.2	11.4	2.5	$4.4^{.01}$
Bryophyte	ND		1.8	2.6	5.2	5.8	$3.4^{.05}$
Lichen	ND		0.0		0.0		0.0
Total	ND		18.5		26.7		$8.2^{.01}$
Site 5							
Graminoid	ND		15.6	9.5	20.4	10.2	$4.8^{.001}$
Dwarf shrub	ND		4.0	2.7	8.3	3.4	$4.3^{.01}$
Bryophyte	ND		0.1		0.6		0.5
Lichen	ND		0.0		0.0		0.0
Total	ND		19.6		28.7		$9.1^{.01}$
Birch and Ericaceous Shrub Tundra							
Site 6							
Graminoid	10.0		1.1	3.7	4.6	0.3	$3.5^{.05}$
Dwarf shrub	43.0		0.0		0.0		0.0
Bryophyte	3.0		12.2	25.5	51.7	8.5	$39.5^{.01}$
Lichen	14.0		0.0		0.0		0.0
Total	70.0		13.4		56.7		$43.3^{.01}$
Site 7							
Graminoid	ND		4.0	6.0	14.2	19.6	$10.2^{.05}$
Dwarf shrub	ND		0.0		0.6		0.6
Bryophyte	ND		6.8	5.2	38.1	28.9	$31.3^{.01}$
Lichen	ND		0.0		0.0		0.0
Total	ND		12.1		54.9		$42.8^{.01}$
Sedge-Shrub Tundra							
Site 8							
Graminoid	30.0	11.5	4.6	2.1	22.3	10.4	$17.7^{.001}$
Dwarf shrub	17.2	10.1	2.0	3.5	5.0	1.4	$3.0^{.05}$
Bryophyte	24.6	21.3	2.1	3.8	5.9	1.6	$3.8^{.01}$
Lichen	12.6	9.9	0.0		0.0		0.0
Total	84.4		8.7		33.2		$24.5^{.001}$
Site 9							
Graminoid	13.2	11.8	1.0		1.5		0.5
Dwarf shrub	56.7	8.0	3.4	8.0	14.8	3.1	$11.4^{.01}$
Bryophyte	14.1	10.3	0.0		2.6	2.3	$2.6^{.01}$
Lichen	7.5	8.9	0.0		0.0		0.0
Total	91.5		4.4		18.9		$14.5^{.001}$

*At each site cover was estimated in ten 1-m × 1-m permanent plots.

† t statistic for paired t test comparing 1978 and 1979 cover values with level of significance indicated.

ND = No determination.

[illegible] the footslope of Nimrod Hill in July 1978, one year after [illegible] upslope from site 1 (stakes in mid foreground [illegible]

[illegible] the footslope of Nimrod Hill in July 1979, two years [illegible] Note abundant fruiting heads of Eriophorum vaginatum

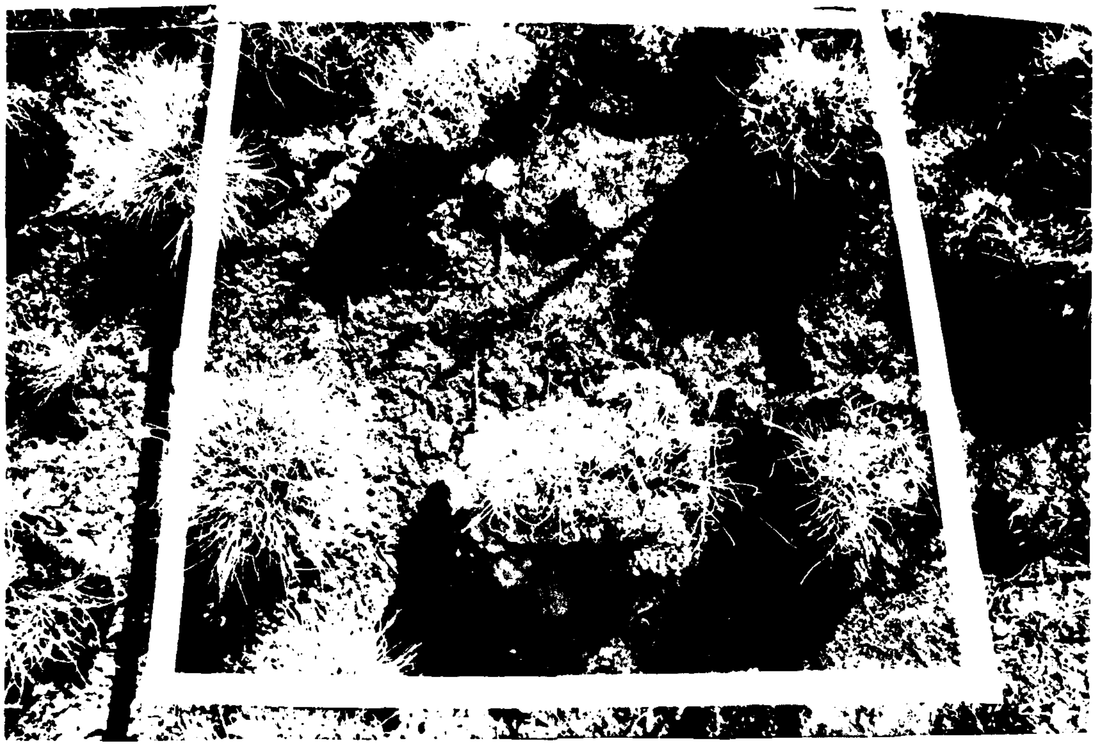

Figure 7. Vertical closeup view of 1 m × 1 m plot at site 1 in burned sedge tussock shrub tundra on Nimrod Hill in July 1978, one year after the tundra fire. Note resprouting Eriophorum vaginatum tussocks.

Figure 8. Closeup view of same 1 m × 1 m plot as pictured in Figure 7 in July 1979, two years after the tundra fire. Note increased resprouting and fruiting of Eriophorum tussocks. Small white dots in the inter-tussock space are Eriophorum fruits.

Table 3. Values for selected species sampled at four sedge tussock-shrub tundra sites on the footslope of Nimrod Hill in the Seward Peninsula.

	*Frequency**				*Cover (%)*				*Density (shoots/m²)*				*Seedlings††*				*Tillers††*			
	1973	*1978*	*1979*	*Diff.†*	*1973*	*1978*	*1979*	*Diff.*	*1973*	*1978*	*1979*	*Diff.*	*1973*	*1978*	*1979*	*Diff.*	*1973*	*1978*	*1979*	*Diff.*
Site 2***																				
Dwarf shrubs																				
Rubus chamaemorus	4	10	10	0	0.9	1.6	4.1	2.6	ND	50	163	$113^{.01}$								
Ledum palustre	10	10	10	0	9.3	1.2	3.4	$2.2^{.01}$	ND	59	90	$31^{.01}$								
Vaccinium uliginosum	10	1	1	0	9.8	0.1	0.1	0	ND	2	2	0								
Vaccinium vitis-idaea	10	10	10	0	6.9	0.8	1.3	$0.6^{.01}$	ND	43	126	$83^{.01}$								
Betula nana	9	3	5	2	6.3	0.1	0.1	0	ND	1	2	1								
Graminoids																				
*Eriophorum vaginatum***	10	10	10	0	34	17	20	3	ND	4.5	5.2	0.7	ND	54	57	3	ND	0	0	0
Carex bigelowii	9	9	10	1	9.2	0.6	1.0	0.4	ND	13	18	5	ND	2	4	2	ND	0	0	0
Calamagrostis canadensis	0	5	5	0	0	0.3	0.7	0.4	ND	6	15	9								
Site 3																				
Dwarf shrubs																				
Rubus chamaemorus		9	9	0		1.6	2.5	0.9		16	68	$52^{.01}$								
Ledum palustre		10	10	0		2.8	2.8	0		41	56	15								
Vaccinium uliginosum		6	7	1		0.5	0.5	0		4	13	9								
Vaccinium vitis-idaea		10	10	0		0.5	0.5	0		25	43	$18^{.01}$								
Betula nana		4	4	0		0.2	0.3	0.1		2	3	1								
Graminoids																				
*Eriophorum vaginatum***		10	10	0		19	20	1		4.2	4.8	0.6		22	32	$10^{.01}$		0	23	$23^{.01}$
Carex bigelowii		7	7	0		0.5	0.5	0		7	11	4		6	2	-4		0	0	0
Calamagrostis canadensis		7	9	2		0.4	0.8	0.4		0.4	18	$11^{.01}$								
Site 4																				
Dwarf shrubs																				
Rubus chamaemorus		10	10	0		4.8	7.9	$3.1^{.01}$		51	162	$111^{.01}$								
Ledum palustre		10	10	0		0.6	1.3	$0.7^{.01}$		20	24	4								
Vaccinium uliginosum		10	10	0		0.5	1.1	$0.6^{.01}$		16	24	$8^{.01}$								
Vaccinium vitis-idaea		10	10	0		0.5	0.5	0		12	16	4								
Betula nana		4	6	2		0.2	0.2	0		1	2	1								
Graminoids																				
*Eriophorum vaginatum***		10	10	0		8	8	0		3.2	3.5	0.3		60	35	-25		0	14	$14^{.01}$
Carex bigelowii		4	4	0		0.3	0.6	0.3		3	5	2		28	73	45		0	41	41
Calamagrostis canadensis		0	0	0		0	0	0		0	0	0								
Site 5																				
Dwarf shrubs																				
Rubus chamaemorus		10	10	0		1.7	3.9	$2.2^{.01}$		23	48	$25^{.01}$								
Ledum palustre		8	10	2		0.5	1.1	$0.6^{.01}$		10	21	$11^{.01}$								
Vaccinium uliginosum		10	10	0		0.5	1.2	$0.7^{.01}$		8	23	$16^{.01}$								
Vaccinium vitis-idaea		9	9	0		0.5	0.5	0		14	23	9								
Betula nana		5	5	1		0.2	0.2	0		1	2	1								
Graminoids																				
*Eriophorum vaginatum***		10	10	0		14	19	5		4.0	4.4	0.4		15	18	3		0	17	$17^{.01}$
Carex bigelowii		7	8	1		7	0.4	0.1		2	5	3		1	5	4		0	0	0
Calamagrostis canadensis		2	2	0		2	0.1	0		1	1	0								

* Number of 1-m× 1-m quadrats in which species occurs (of the 10 quadrats sampled at each site).

† Comparing 1978 and 1979 values with level of significance indicated.

** Density here refers to number of tussocks/m^2.

†† Seedling and tiller data not collected for species other than graminoids (impossible to differentiate between seedlings and sprouts).

*** Only site 2 sampled in 1973.

Table 4. Mean density values* (stalks/m²) of flowering and/or fruiting heads of cottongrass tussocks (*Eriophorum vaginatum*) and bluejoint grass (*Calamagrostis canadensis*) in mid-July 1978 and 1979 following a July 1977 tundra fire in the Seward Peninsula.

	1978		*1979*		*Diff. between*	*Level of*
	Mean	*Std. dev.*	*Mean*	*Std. dev.*	*1978 and 1979*	*significance*†
Eriophorum vaginatum						
Site 1	4.5	4.1	59.6	37.6	55.1	0.001
Site 2	4.5	4.9	44.9	54.9	40.4	0.05
Site 3	5.3	4.7	22.4	35.7	17.1	0.2
Site 4	2.0	2.6	22.1	20.5	20.1	0.01
Site 5	6.8	8.2	38.5	25.7	31.7	0.01
Calamagrostis canadensis						
Site 1	0.0		8.0	8.9	8.0	
Site 2	0.0		3.3		3.3	
Site 3	0.0		4.6		4.6	
Site 6	0.0		5.1		5.1	
Site 7	0.0		74.2	94.1	74.2	

*Mean values for ten 1-m × 1-m plots at each of nine sites along the topographic gradient of Nimrod Hill near Imuruk Lake.
† Tests of significant differences made using a paired t-test indicated by probability levels.

of the ground surface, probably due to the melting of ground ice. This subsidence of the ground surface around supporting rock columns resulted in mounds and hummocks up to 1 m high (Fig. 9), which gave the appearance of frost-heaved rocks.

Groundwater movement downslope, possibly from melting ice on the backslope, was suggested by observations made in July 1979 of 1) coarse mineral loam of a color and texture suggesting an origin on the backslope which had issued from the footslope in several areas, and 2) shallow V-shaped channels which were beginning to form on the footslope through surface subsidence. According to Chapin et al. (1979) the bright green color of the cottongrass tussocks in these new drainages suggests groundwater movement.

Vegetation

Prior to the 1977 fire, the birch and ericaceous shrub tundra community on the Nimrod Hill backslope (sites 6 and 7) was dominated by dwarf shrubs such as blueberry, dwarf birch, lingonberry and Labrador tea, by *Carex bigelowii*, and by lichens such as *Cetraria cucullata*, *C. islandica*, *Cladonia gracilis* and *C. rangiferina* (Table 5). On the tops of the well-vegetated, turf-banked frost boils within this community, the dwarf shrubs, alpine bearberry (*Arctostaphylos alpina*), crowberry and netted willow (*Salix reticulata*) were dominant. Exposed rocks on these frost boils were covered with the lichens *Alectoria nigricans*, *Cetraria cucullata* and *Cladonia gracilis*, and the moss *Rhacomitrium lanuginosum* (Table 5).

The 1977 fire severely burned this birch and ericaceous shrub tundra community. Little or no resprouting of species present before the fire occurred during the following two years. Virtually all vegetation recovery has resulted from colonizing bryophytes, graminoids and forbs (Fig. 4). One year after the fire the total living plant cover was about 14% and was composed mainly of seedling graminoids (*Carex bigelowii* and *Eriophorum vaginatum*) and bryophytes (*Marchantia polymorpha* and *Ceratodon purpureus*) (Table 5, Fig. 11). In addition, there were small colonies of nonflowering and short-stemmed bluejoint grass and some scattered individuals of fireweed. The tops of the elongate, turf-banked frost boils remained completely unvegetated, with conspicuous cracks and exposed mineral soil and rocks which appeared to have been frost churned (Fig. 11). The only plants on the surfaces of these boils were a few individuals of chickweed (*Stellaria longipes*), *Minuartia rossii* and bluejoint grass at site 7 (Table 5).

Between the first and second years following the fire, there was a large increase in living plant

Figure 9. Small (0.5-m-diam and 0.7-m-high) mound in birch and ericaceous shrub tundra community on the backslope of Nimrod Hill, probably resulting from subsidence of the ground surface around rocks. Note tearing of the organic mat and abundant fireweed and bluejoint grass (background) and sedge seedlings (foreground).

cover in the non-frost-boil areas: from about 14% cover in 1978, to 55% in 1979, at both backslope sites (Fig. 4, 9, 10 and 12). This increased cover was due almost entirely to the growth and expansion of the species which colonized the site during the first year following the fire (Table 5, Fig. 11 and 12). The moss, *Ceratodon purpureus* made a 400% increase from about 8% cover in 1978 to 40% cover in 1979. Expansion, through tillering, of the *Carex bigelowii* seedlings, established in 1978, was also striking (Fig. 9 and 10). There was also a conspicuous increase in the density and cover of bluejoint grass together with increased height growth and flowering of this species. Whereas no flowering and/or fruiting stalks of bluejoint grass were seen in 1978, almost all shoots were reproducing by 1979 (Table 4). Significant increases in the density and flowering of fireweed also occurred during the second year and a few individuals of marsh fleabane (*Senecio congestus*) were present for the first time.

In 1979, the tops of the frost boils remained bare mineral soil and rock except for the slight expansion of the chickweed and *Minuartia rossii* populations at site 7. Only at site 7 (Table 5) was there any evidence of the resprouting of the dwarf shrubs abundant before the fire; here blueberry showed a few resprouting shoots in four plots.

Sedge-shrub tundra (site 8 and 9)

Soils

On the level, upland crest of Nimrod Hill (site 8) and onto the northeast-facing backslope (site 9), the soil moisture environment is very poorly drained. The only frost features at sites 8 and 9 are low-centered polygons on the level hill crest of site 8. In pre-fire 1973, there was a fairly thick accumulation of organic material at both sites, 30–35 cm at site 8 and 20–30 cm at site 9. Much of this thickness was attributed to the buildup of *Sphagnum* moss mats at both sites. Burning at these sites in 1977 was quite patchy (Fig. 13), with the *Sphagnum* moss mats generally remaining unburned but apparently scorched and dead as suggested by their tan color and dryness two

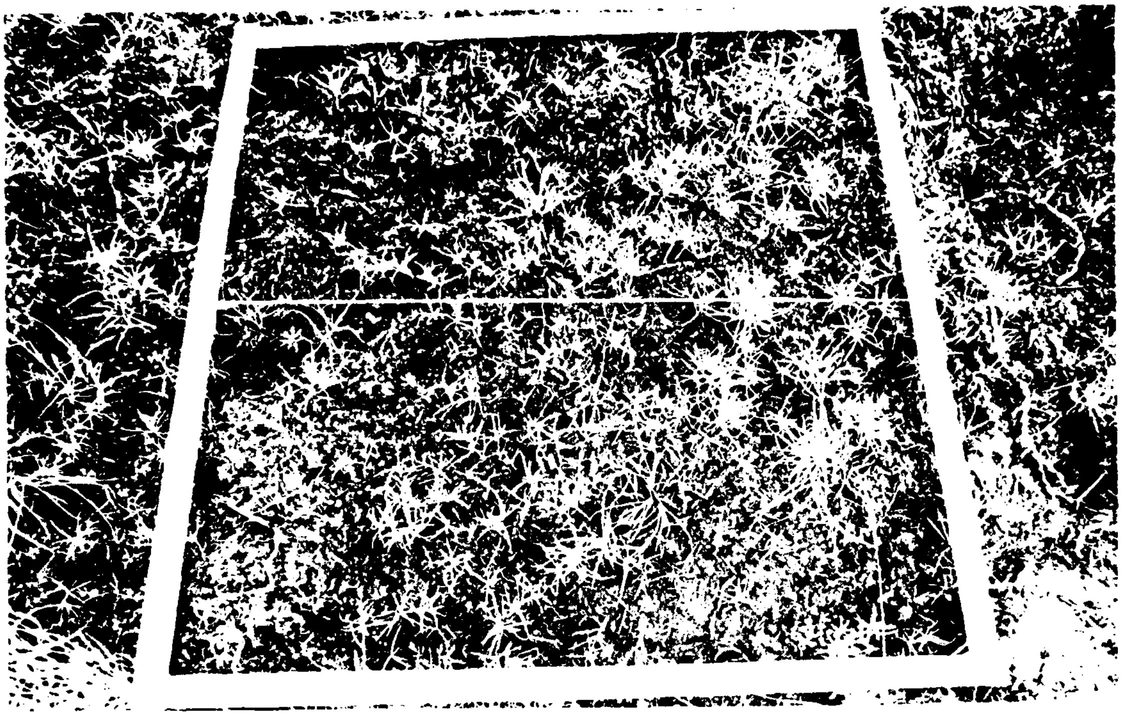

Figure 10. Vertical closeup of plot 1 at site 7 in a burned birch and ericaceous shrub tundra community on Nimrod Hill two years after the tundra fire. Note abundant tillering seedlings of Carex bigelowii. Fireweed is also visible in lower right corner of the plot.

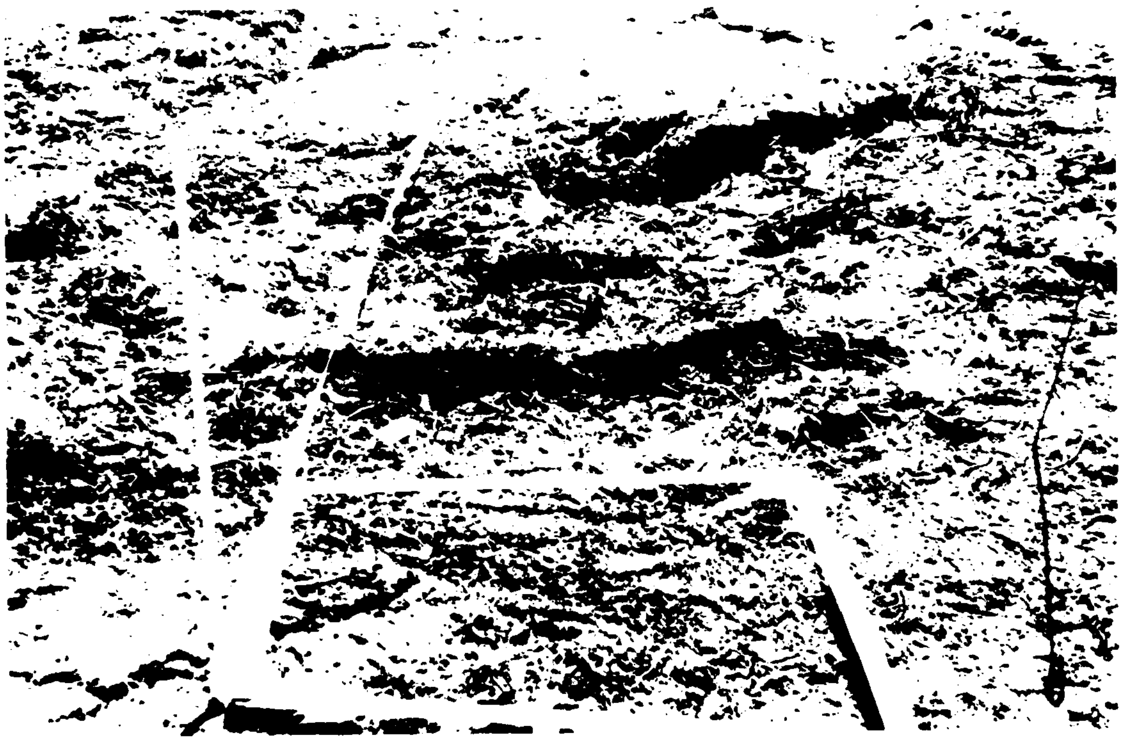

Figure 11. Burned birch and ericaceous shrub tundra community in July 1978, one year after the fire, site 7. Vegetation and soil organics have burned off revealing turf-banked frost boils. Little or no vegetation has recovered and thaw depths have increased greatly over prefire conditions.

Figure 12. Same view (as in Fig. 11) of burned shrub tundra at site 7 in July 1979, two years after the fire. Note large increase in vegetation cover due to establishment of bluejoint grass, fireweed, marsh fleabane, sedges and successional mosses.

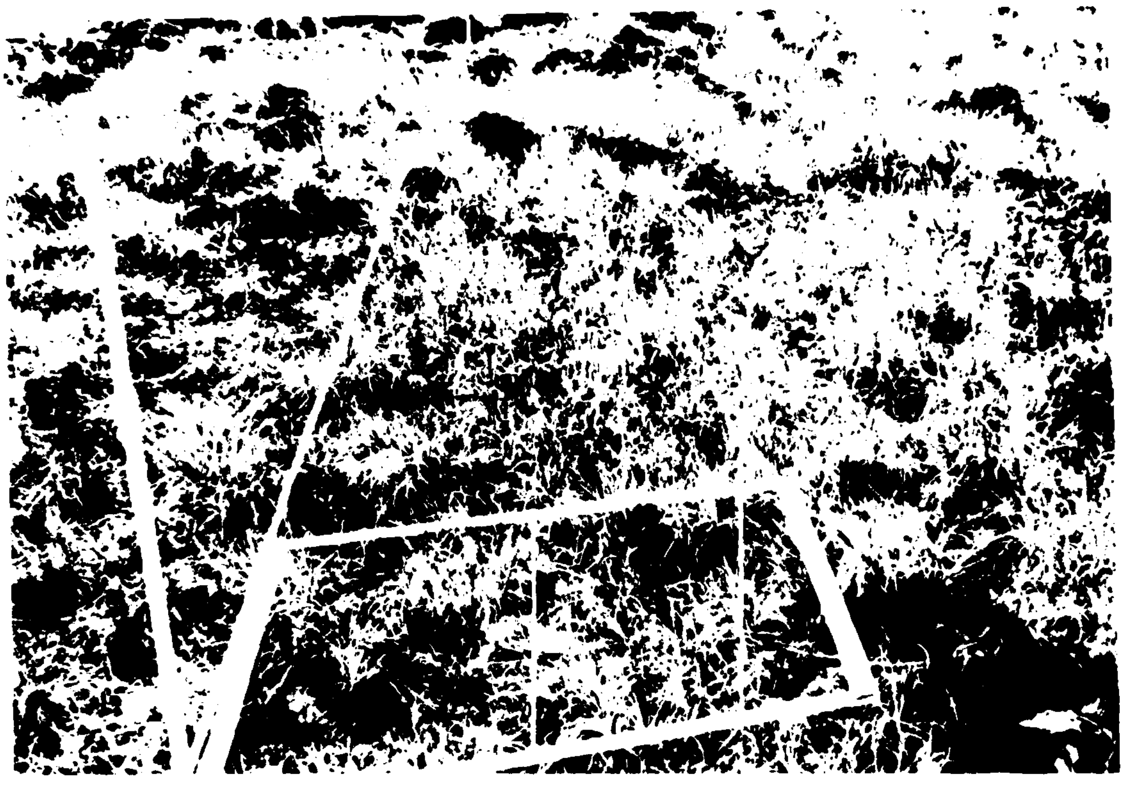

Figure 13. July 1979 view of sedge shrub tundra community on the crest of Nimrod Hill, site 8. Note vigorous resprouting of the sedges, Carex aquatilis *and* Eriophorum scheuchzeri.

Table 5. Values for species sampled in a birch and ericaceous shrub tundra community at site 7 before and after a tundra fire on Nimrod Hill in the Seward Peninsula, Alaska.

Values given separately for the tops of elongate turf-banked frost boils and the surrounding tundra.

	Prefire (1973)				*One yr after (1978)*						*2 yrs after (1979)*					
	Non-frost boils		*Frost boils*		*Non-frost boils*			*Frost boils*			*Non-frost boils*			*Frost boils*		
Species	*Freq.**	*Cover (mean %)*	*Freq.*	*Cover (mean %)*	*Freq.*	*Cover (mean %)*	*Density (shoots/m²)*	*Freq.*	*Cover (mean %)*	*Density (shoots/m²)*	*Freq.*	*Cover (mean %)*	*Density (shoots/m²)*	*Freq.*	*Cover (mean %)*	*Density (shoots/m²)*
Dwarf shrubs																
Betula nana	10	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ledum palustre	9	6	0	0	1	1	1	0	0	0	1	1	1	0	0	0
Vaccinium vitis-idaea	10	7	10	4	0	0	0	0	0	0	0	0	0	0	0	0
Vaccinium uliginosum	10	18	10	8	2	1	1	0	0	0	4	2	0	0	0	0
Arctostaphylos alpina	0	0	6	5	0	0	0	0	0	0	0	0	0	0	0	0
Salix sp.	7	1	7	1	0	0	0	2	1	1	0	0	0	2	1	1
Empetrum nigrum	8	5	10	4	0	0	0	0	0	0	0	0	0	0	0	0
Salix reticulata	0	0	10	1	0	0	0	0	0	0	0	0	0	0	0	0
Graminoids																
Carex bigelowii																
Adult	10	10	6	1	0	0	0	0	0	0	5	1	13	0	0	0
Seedling	ND		ND		10	1	19	0	0	0	10	3	25	0	0	0
Tillers	ND		ND		0	0	0	0	0	0	10	4	100	0	0	0
Eriophorum vaginatum																
Seedlings	ND		ND		8	1	30	0	0	0	1	1	1	0	0	0
Tillers	ND		ND		0	0	0	0	0	0	0	0	0	0	0	0
Calamagrostis canadensis	0	0	0	0	7	4	28	6	1	9	8	15	117	10	1	19
Forbs																
Petasites frigidus	10	2	10	1	1	1	1	1	1	1	1	1	2	1	1	1
Epilobium angustifolium	0	0	0	0	5	1	1	1	1	1	8	1	8	1	1	2
Senecio congestus	0	0	0	0	0	0	0	0	0	0	2	1	1	0	0	0
Stellaria	0	0	0	0	0	0	0	6	2	10	0	0	0	6	3	100
Sagina intermidia	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1
Bryophytes																
Ceratodon purpureus	0	0	0	0	10	7	ND	6	3	ND	10	51	ND	8	25	ND
Marchantia polymorpha	0	0	0	0	9	1	ND	4	1	ND	9	1	ND	2	1	ND
Polytrichum ssp.	0	0	6	1	1	1	ND	1	1	ND	1	1	ND	1	1	ND
Sphagnum spp.	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhacomitrium lanuginosum	0	0	10	20	0	0	0	0	0	0	0	0	0	0	0	0
Lichens																
Cetraria cucullata	10	5	10	4	0	0	0	0	0	0	0	0	0	0	0	0
Cladonia gracilis	10	9	10	4	0	0	0	0	0	0	0	0	0	0	0	0
Alectoria nigricans	0	0	10	4	0	0	0	0	0	0	0	0	0	0	0	0

*Number of 1-m × 1-m quadrats in which species occurs/no. of quadrats sampled on that site × 10.

ND - no determination.

years after the fire. At site 9, there were charred and more deeply burned pockets between moss hummocks, where about 13 cm of the organic horizon remained. This suggested that the removal of the top 10 cm of this horizon was probably related to the severe burning of the dwarf shrubs in these pockets. Burning at site 8 was apparently less severe but also uneven. Post-fire determinations of organic horizon thickness varied from 15–30 cm, suggesting the removal of from 5–15 cm of the organic horizon.

Thaw depths were significantly greater one year after the fire (1978) than before the fire (1973) at site 8 on the level hill crest, having increased by 7.6 cm or 32% (Table 1). A further increase in thawing of 11.5 cm (37%) took place here during the second year following the fire. At site 9, on the northeast-facing backslope, little or no increase in thaw depth was observed over pre-fire depths during the first year following the fire. However, an increase of 11.6 cm (47%) occurred during the second year. Rapid post-fire thawing at site 9 may have been inhibited by the large scorched *Sphagnum* mats.

Vegetation

Pre-fire vegetation (1973) at both sites 8 and 9 was fairly similar in that dwarf shrubs, sedges and *Sphagnum* mosses were important (Tables 2 and 6). However, the wetter level hilltop (site 8) community was dominated by single-stemmed sedges (*Carex aquatilis* and *Eriophorum scheuchzeri*), while at site 9 dwarf shrubs were clearly dominant (Table 6). The presence of low-centered polygons and the absence of slope drainage at site 8 may account for this shift in dominance. Little vegetation recovery (less than 10%) occurred at either site one year after the fire (Table 2, Fig. 4). Most of the dwarf shrub species present before the fire had started to resprout at both sites, with cloudberry clearly the most prolific (Table 6). *Carex aquatilis* showed limited resprouting at both sites, while both *Ceratodon purpureus* and *Marchantia polymorpha* were occasional at site 8 and rare at site 9.

In contrast with this small first year recovery, a large (15–25%) increase in plant cover occurred during the second year (1979) as a result of the accelerated resprouting of dwarf shrubs at both sites and of the sedges at site 8. Of the shrubs, cloudberry showed a three- to five-fold increase in cover and reached levels equal to those before the fire. Blueberry also showed a more rapid recovery here than at other sites along the transect. However, by far the largest increase in density and cover was made by *Carex aquatilis* (and to a lesser extent *Eriophorum scheuchzeri*) at site 8 (Fig. 13), which reached cover values of about 23%, near the pre-fire level of about 30% (Fig. 4, Table 6). Both dwarf birch and blueberry were fairly important at sites 8 and 9 before the fire but showed little or no resprouting during the following two years. Crowberry was also present at both sites before the fire but showed no sign of post-fire recovery. The dead *Sphagnum* mats, apparently killed by the heat from the fire or by the removal of moisture, also showed no sign of recovery. Few species, with the exception of cloudberry, were seen to resprout out of these mats at site 9. Fireweed is the only vascular plant species at sites 8 and 9 that was not sampled there before the fire.

DISCUSSION AND CONCLUSIONS

From the above results, it is clear that the 1977 fire had different effects on each of the three tundra communities located along the slope of Nimrod Hill. Although the results are preliminary and based on only two years of post-fire recovery data, some similarities and differences with respect to the effects and role of fire in these three communities can be discussed. Certain of the changes resulting from fire along the gradient of Nimrod Hill are summarized in Figure 14.

The sedge tussock–shrub community on the footslope of Nimrod Hill appears to have been least affected by the fire in terms of the severity of burning, change in thaw depths and post-fire revegetation. The severity of burning here was light to moderate, and thaw depths did not increase by more than 10–15 cm during the following two years (Fig. 14). Initial revegetation following the fire appears to be almost completely due to the vegetative resprouting of the vascular plant species present before the fire. Hence, much of pre-fire species composition is apparently restored fairly quickly, although little lichen and moss recovery has taken place during these first two years. The relative importance of graminoid tussocks over dwarf shrubs has significantly increased as a result of the fire. This is due to the almost immediate post-fire resprouting of cottongrass tussocks in contrast with the relatively slow resprouting of dwarf shrubs.

A model showing post-fire successional changes in tussock–shrub tundra is proposed in Figure 15. After some unknown interval of time, the dwarf shrubs and mosses would eventually grow up around the cottongrass tussocks, result-

Table 6. Values for species sampled at two sedge-shrub tundra sites on the crest (site 8) and northeast-facing backslope (site 9) of Nimrod Hill in the Seward Peninsula, Alaska, after a 1977 tundra fire.

	Site 8								*Site 9*							
	Prefire (1973)		*1 yr after (1978)*			*2 yrs after (1979)*			*Prefire (1973)*		*1 yr after (1978)*			*2 yrs after (1979)*		
Species	Freq.*	Cover†	Freq.	Cover	Density (shoots/m²)	Freq.	Cover	Density (shoots/m²)	Freq.	Cover	Freq.	Cover	Density (shoots/m²)	Freq.	Cover	Density (shoots/m²)
Dwarf shrubs																
Rubus chamaemorus	10	3.3	9	1.2	24	9	3.3	45	10	13.1	10	2.6	53	10	12.2	129
Ledum palustre	10	3.9	5	0.4	4	7	0.7	7	10	12.0	7	0.3	4	8	0.6	16
Vaccinium uliginosum	1	0.4	4	0.3	6	5	1.1	21	7	3.7	8	0.5	10	10	1.9	35
Vaccinium vitis-idaea	10	2.8	3	0.2	2	4	0.2	3	10	15.5	6	0.3	2	7	0.3	5
Betula nana	10	5.9	1	0.1	0	2	0.1	0	9	11.3	0	0	0	0	0	0
Graminoids																
Carex aquatilis	10	20.0	10	4.0	63	10	21.0	136	10	13.2	10	0.4	5	7	0.4	6
Eriophorum scheuchzeri	6	10.0	8	0.6	15	8	1.5	42	0	0.0	0	0	0	0	0	0
Bryophytes																
Ceratodon purpureus	0	0	8	0.9	ND	9	1.2	ND	0	0	0	0	0	10	2.5	0
Marchantia polymorpha	0	0	8	0.7	ND	8	2.5	ND	0	0	0	0	0	4	0.3	0
Polytrichum spp.	0	0	9	0.6	13	10	2.3	ND	0	0	0	0	0	0	0	0
Sphagnum spp.	10	26.0		dead			dead		10	13.0		dead			dead	
Lichens																
Cetraria cucullata	10	3.6	0	0	0	0	0	0	7	1.9	0	0	0	0	0	0
Cladonia gracilis	10	9.0	0	0	0	0	0	0	7	5.4	0	0	0	0	0	0

*Number of 1-m × 1-m plots in which the species occurs (ten plots sampled).
†Mean percent cover averaged over 10 plots.

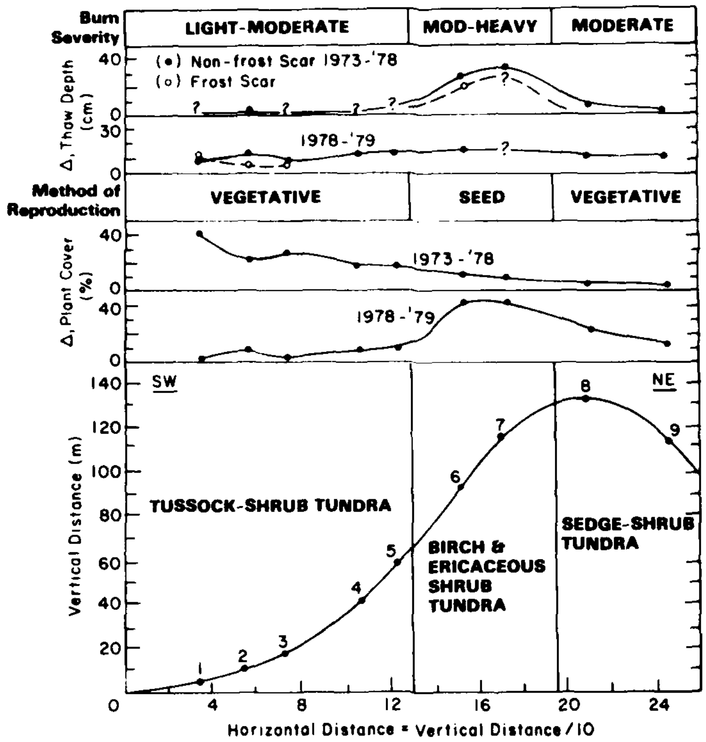

Figure 14. Summarized fire effects and postfire recovery during 1978 and 1979 from the tundra fire on Nimrod Hill.

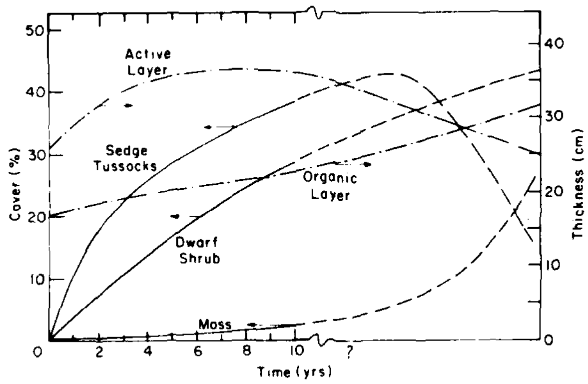

Figure 15. Hypothetical model showing changes in vegetation (growth forms), soil active layer and organic layer thickness following fire in tussock-shrub tundra ecosystems.

ing in the senescence of the tussocks and thinning of the active layer. Such a successional process involving the buildup of organics (paludification) and burial of tussocks has been noted on a large scale in the Seward Peninsula (Hopkins 1972, Racine and Anderson 1979, Melchior 1979). Fire would prevent such conditions from developing in tussock shrub tundra through removal of some of the vegetation and organic soil from around tussocks.

Frost action, leading to the formation of mud circles in tussock-shrub tundra, would also promote vigorous tussocks by disrupting the organic mat and the mosses as well as the dwarf shrubs growing up around them. Mud circles can serve as a substrate for the establishment of new cottongrass tussocks (Hopkins and Sigafoos 1951). Evidence obtained on Nimrod Hill suggests that fire may stimulate frost action, leading to mud circle formation; in 1973, extensive probing in the tussock-shrub community suggested that the summer active layer rarely reached into the mineral soil (condition on the right in Fig. 15). However, by 1979, two years after the fire, thawing appeared to extend below the organic horizon into the mineral soil horizons (condition on the left in Fig. 15). This would promote the formation of ice lenses in the mineral soil during freeze-thaw cycles so that the physical movement and churning necessary for frost action would be possible.

The post-fire origin of resprouting dwarf shrubs is presumably stems, roots, and/or rhizomes buried in the remaining organic soil layer. Dwarf shrub species showed differential resprouting rates following the fire on Nimrod Hill. These differences might be related to the depth or location of their underground stems or roots in relation to the severity of burning. Dwarf shrubs which penetrate deep into the organic mat or grow into the tussock mass might escape fire and recover faster than those nearer the surface.

Shaver and Cutler (1979) have determined the vertical distribution of biomass above and belowground for different species in tussock-shrub tundras in various parts of Alaska; they found for example that crowberry and lingonberry have most of their below-ground biomass located near the surface. In the Seward Peninsula, we found no evidence of recovery of crowberry in 2- or 7-year-old burns. Lingonberry resprouted abundantly but these sprouts were almost always located on the surface or sides of tussocks (K. Devereaux, Hampshire College, Amherst, Mass., personal communication), suggesting that they escaped burning within the tussock mass. In the sedge-shrub tundra community at sites 8 and 9 on Nimrod Hill, where there are no tussocks, lingonberry was abundant before the fire but showed little post-fire resprouting. Vigorous post-fire resprouters such as Labrador tea and cloudberry have a high proportion of their biomass in the deeper soil organic layers (Shaver and Cutler 1979, Flinn and Wein 1977).

Fire had the most drastic effects on the birch and ericaceous shrub tundra community located on the better drained backslope of Nimrod Hill. The severity of burning was moderate to heavy, with thaw depths increasing greatly in the first year following the fire; by the second year there was evidence of surface subsidence and the formation of hummocks where there were supporting rock columns. Transport of mineral soil by groundwater moving downslope from this area may result in changes in slope topography. Mackay (1977) reported that a burned hillslope at Inuvik (N.W.T.) subsided nearly 50 cm during the 8 years following a 1968 fire. Cody (1964) described similar subsidence and formation of hummocky terrain 3 years after a taiga fire in the Mackenzie Delta.

Vegetation recovery in this burned birch and ericaceous shrub community is different from that in either of the other communities; all regeneration appears to be from seed by species of minor importance in the pre-fire community rather than from the resprouting of species abundant before the fire. The structure and composition of this community appear to have been changed drastically by the fire. The dwarf shrubs which were dominant before the fire have been replaced by graminoid sedges, grasses and several forbs. Successional bryophytes have also played an important role in post-fire vegetation recovery in this backslope community, unlike their minor role in the other tussock-shrub and sedge-shrub communities. It might be argued that these differences are due to the greater severity of burning of this particular community on Nimrod Hill. However, observation and aerial reconnaissance over much of the 1977 burn suggest that the birch and ericaceous shrub tundra community consistently burns more severely because of its more xeric topographic position and the absence of fire resistant tussocks.

What is the origin of the seed for the seedling revegetation of the burned birch and ericaceous shrub community? Three possible origins in

clude (1) seeds buried in the organic soil layers which are exposed by fire, (2) seeds dispersed onto the burn immediately following fire by plants growing in adjacent unburned tundra, and (3) seeds produced in the burned area by the abundant flowering stimulated by fire. This third source is discounted as an initial seed source because neither cottongrass tussocks nor bluejoint grass flowered abundantly until the second year following the 1977 fire. We have no data to test the second hypothesis. There is some recent evidence to support the buried seed origin. McGraw (1979) determined that a large, viable seed bank (3367.2 seeds/m²) was contained in the organic horizon of a tussock–shrub tundra community in interior Alaska. Seeds of *Eriophorum vaginatum* and *Carex bigelowii* comprised 60% of this total and these seeds were at depths greater than 15 cm, with *Carex* seed density actually increasing with depth in the organic mat. Hence, the relatively deeply buried seed bank of these two sedge species would be available for recolonizing even fairly severely burned areas such as those on the Nimrod Hill backslope.

In the sedge–shrub community on the crest and northeast facing backslope of Nimrod Hill, both the severity of burning and the post-fire revegetation were inhibited by the presence of *Sphagnum* moss mats. Although these mats did not burn, they appear to have been killed by the fire. These *Sphagnum* mats have undoubtedly reduced the rate of increase in the thickness of the active layer. Vegetation recovery in the sedge-shrub tundra community has proceeded by vegetative resprouting of species present before the fire, but at a slower rate than in the tussock–shrub tundra community. Few shoots (except for cloudberry) appear to grow out of the dead *Sphagnum* mats. However, as in both of the other burned communities on Nimrod Hill, sedges appear to have been stimulated by the fire, and are resprouting earlier than dwarf shrubs.

LITERATURE CITED

Chapin, F.S. III, K. Van Cleve and M.C. Chapin (1979) Soil temperature and nutrient cycling in the tussock growth form of *Eriophorum vaginatum*. *Journal of Ecology*, vol. 67, p. 169–189.

Cody, W.J. (1964) *Reindeer range survey 1957 and 1963*. Ottawa: Plant Research Institute, Canadian Department of Agriculture.

Flinn, M.A. and R.W. Wein (1977) Depth of underground plant organs and theoretical survival during fire. *Canadian Journal of Botany*, vol. 55, p. 2550–2554.

Hall, D., J. Brown and L. Johnson (1978) The 1977 tundra fire in the Kokolik River area of Alaska. *Arctic*, vol. 31, p. 54–58.

Holowaychuk, N. and N.E. Smeck (1979) Soils of the Chukchi-Imuruk area. In *Biological Survey of the Bering Land Bridge National Monument* (H.R. Melchior, Ed.). Revised Final Report. Alaska Cooperative Park Studies Unit, University of Alaska, Fairbanks.

Hopkins, D.M. (1963) Geology of the Imuruk Lake area, Seward Peninsula, Alaska. *USGS Bulletin* 1141-C.

Hopkins, D.M. (1972) The paleogeography and climatic history of Beringia during late Cenozoic time. *Inter-Nord*, vol. 12, p. 121–150.

Hopkins, D.M. and R.S. Sigafoos (1951) Frost action and vegetation patterns on Seward Peninsula, Alaska. *USGS Bulletin* 974-C, p. 51–100.

Johnson, L. and K. Van Cleve (1976) Revegetation in arctic and subarctic North America: A literature review. USA Cold Regions Research and Engineering Laboratory, CRREL Report 76-15. ADA 027406.

Mackay, R.J. (1977) Changes in the active layer from 1968–1976 as a result of the Inuvik fire. Report of Activities, Geological Survey of Canada, Paper 77-1B, p. 273–275.

McGraw, J.B. (1979) Seed bank size and distribution of seeds in cottongrass tussock tundra, Eagle Creek, Alaska. Masters Thesis, Duke University, Durham, N.C.

Melchior, H.R. (1979) Mining, reindeer, climate and fire: Major historical factors affecting the Chukchi-Imuruk environment. In *Biological Survey of the Bering Land Bridge National Monument* (H.R. Melchior, Ed.). Revised Final Report, Alaska Cooperative Park Studies Unit, University of Alaska, Fairbanks.

Ostle, B. (1963) *Statistics in Research*. Iowa City: Iowa State University Press.

Racine, C.H. (1979) The 1977 tundra fires in the Seward Peninsula, Alaska: Effects and initial revegetation. Bureau of Land Management, Alaska Technical Report 4.

Racine, C.H. and J.H. Anderson (1979) Flora and vegetation of the Chukchi-Imuruk Lake area, Alaska. In *Biological Survey of the Bering Land Bridge National Monument* (H.R. Melchior, Ed.). Revised Final Report. Alaska Cooperative Park Studies Unit, University of Alaska, Fairbanks.

Racine, C.H. and M.M. Racine (1979) Tundra fires and two archeological sites in the Seward Peninsula, Alaska. *Arctic*, vol. 32, p. 76–79.

Schmitt, R.C. (1979) The influence of microtopography and fire on the active layer depth on the Seward Peninsula, Alaska. Unpublished course paper, Forestry Department, University of Massachusetts, Amherst.

Shaver, G.R. and J.C. Cutler (1979) The vertical distribution of live vascular phytomass in cottongrass tussock tundra. *Arctic and Alpine Research*, vol. 11, p. 335–342.

Viereck, L.A., J. Foote, C.T. Dyrness, K. Van Cleve, D. Kane and R. Seivert (1979) Preliminary results of experimental fires in the black spruce type of interior Alaska. U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station Research Note PNW-332, 27 p.

Viereck, L.A. and C.T. Dyrness (1980) A preliminary classification system for vegetation of Alaska. U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station General Technical Report PNW-106, 38 p.

Webber, P.J. and J.D. Ives (1978) Damage and recovery of tundra vegetation. *Environmental Conservation*, vol. 5, p. 171–182.

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